Is the right anterior superior temporal sulcus involved in speaker-identity recognition? A study using transcranial direct current stimulation

Dissertation

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List of abbreviations

aSTS	anterior superior temporal sulcus
BOLD	blood oxygenation level dependent
cm	centimeter(s)
IFC	inferior frontal cortex
fMRI	functional magnetic resonance imaging
kΩ	kiloohm
MEG	magnetoencephalography
mA	milliampere
mm	millimeter(s)
min	minute(s)
sec	second(s)
STS/ STG	superior temporal sulcus/ gyrus
tdcs	transcranial direct current stimulation
TL	temporal lobe
TMS	transcranial magnet stimulation
TVA	temporal voice area

Abstract

Neuroimaging studies have revealed regions in the human brain that respond preferentially to human voices. These regions are mostly located along the superior temporal gyrus and sulcus (STG/S). It has been hypothesized that the right anterior STG/S is crucial for voice-identity recognition because the amplitudes of anterior STG/S neuroimaging responses correlate positively with voice-identity recognition performance. Here, my aim was to test this hypothesis by using non-invasive transcranial direct current stimulation (tdcs) in a randomized double blind sham-controlled within-participants design. 24 neurotypical participants were familiarized with four unfamiliar speakers' voices and were then tested on voice-identity and speech recognition. While performing the voice-identity and speech recognition test, participants received anodal, cathodal, and sham tdcs on three different days, respectively. As hypothesized, voice-identity recognition was improved when applying anodal tdcs to the right anterior STG/S as compared to cathodal and sham. However, this was only the case on day three. My results support the hypothesis that the right anterior STG/S is behaviourally relevant for identifying a speaker's voice.

Zusammenfassung

Der Titel der Arbeit lautet wiefolgt: Ist der rechte anteriore superiore temporale Sulcus (aSTS) in die Identifizierung einer sprechenden Person involviert? – Eine transkranielle Gleichstromstimulation des rechten aSTS.

Die meisten Menschen können eine bekannte Person anhand ihrer Stimme erkennen. Dem rechten anterioren superioren temporalen Sulcus (aSTS) wird eine wichtige Rolle bei dieser Stimmidentifizierung zugeschrieben. Darauf deuten kombinierte behaviorale und funktionelle Bildgebungsstudien (fMRT) hin.

In diesem Projekt sollte nun mithilfe von anodaler, kathodaler und sham transkranieller Gleichstromstimulation (tdcs) des rechten aSTS von 24 ProbandInnen ein kausaler Zusammenhang zwischen Verbesserung bzw. Verschlechterung bzw. Gleichbleiben der Stimmerkennung und der Stimulationsart des rechten aSTS gezeigt werden.

Die Arbeitshypothese lautete wie folgt: Die Ergebnisse zur Sprechererkennung (Erkennung von zuvor gelernten Stimmen, sogenannten „recently-familiarised voices“ (Maguinness et al. 2018) verbessern bzw. verschlechtern sich unter anodaler bzw. kathodaler tdcs Stimulation. Weiterhin bleibt die Stimmerkennung unverändert unter sham-tdcs Stimulation des rechten aSTS. In der Kontrollaufgabe, einer Spracherkennungsaufgabe, sollten sich unter dem gleichen Stimulationsmuster keine Veränderungen ergeben, da die Spracherkennung tendenziell der linken Hemisphäre zugeschrieben wird.

Das Experiment war in zwei Teile aufgeteilt: in einen ersten Teil, in welchem die ProbandInnen Stimmen von ihnen vorher unbekannten männlichen Sprechern lernten und deren Erkennung trainierten und in einen darauffolgenden zweiten Teil, in welchem die ProbandInnen tdcs erhielten und dabei Sprechererkennungs- und Spracherkennungsaufgaben ausführten.

Die Anwendung eines Gemischten Modells zur Analyse der Daten mit den festen Faktoren STIMULATIONSART (anodal, kathodal, sham), AUFGABE (Sprecher, Sprache) und TAG (Tag1, Tag2, Tag3) ergab als Ergebnis eine dreifach-Interaktion für die Aufgabe „Sprechererkennung“.

Um diese genauer zu eruieren, wurden weitere Analysen durchgeführt. Diese ergaben, dass die Sprechererkennung am dritten Tag der Stimulation in der anodalen tdcs signifikant besser ware im Vergleich zur kathodalen und sham tdcs.

Auf der Basis des Ergebnisses, dass anodale tdcs des rechten aSTS am dritten Tag der Stimulation mit einer besseren Sprecheridentifizierung im Vergleich zur Sprecheridentifizierung unter der kathodalen und sham Stimulation einherging, kann geschlussfolgert werden, dass anodale tdcs den Zugriff auf im rechten aSTS gespeichertes Wissen über die Identität eines Sprechers erleichtert hat. Ob es sich hierbei um einen Zugriff auf Stimmmodalität-spezifisches Wissen handelt oder vielmehr um allgemeineres, mehrere Modalitäten vereinendes Wissen über die Identität einer Person, ist aus dem Studiendesign nicht ersichtlich.

Hierfür könnte eine Studie angeschlossen werden, welche aus einem Design mit einer zusätzlich eingebauten Aufgabe zur Gesichtserkennung besteht, um neben der Modalität „Stimme“ die Modalität „Gesicht“ zu testen und somit zwischen „stimmspezifischer“ und „allgemeiner“ Identität zu unterscheiden.

Introduction

Communication is essential for everyday life and the ability to recognize the identity of a person is indispensable for successful communication (Bruce and Young 1986, von Kriegstein et al. 2008, Yardley et al. 2008, Young and Bruce 2011).

One of the most important cues for person recognition is the human voice (Papcun et al. 1989, Schweinberger et al. 1997, Sheffert et al. 2002); for reviews see Belin et al. (2004), Kreiman and Sidtis (2011). In humans, as well as in non-human primates, several brain structures are preferentially responsive to human voices (Belin et al. 2000, Fecteau et al. 2004, Shultz et al. 2012); for reviews see Petkov et al. (2009), Mathias and von Kriegstein (2014).

To-date, however, it is unclear whether these regions are critical for voice-identity recognition behaviour. Neuroimaging studies have shown that voice-sensitive regions are located predominantly in the temporal lobe of the human brain (Belin et al. 2000, Binder et al. 2000, von Kriegstein et al. 2003, Fecteau et al. 2004, von Kriegstein and Giraud 2004, von Kriegstein and Giraud 2006, Shultz et al. 2012).

These involve Heschl's gyrus (Formisano et al. 2008, Bonte et al. 2014), planum temporale (von Kriegstein and Giraud 2006, Warren et al. 2006), and most prominently several regions along the superior temporal gyrus/sulcus (STG/S) and middle temporal gyrus (MTG) (Belin et al. 2000, von Kriegstein and Giraud 2004, von Kriegstein et al. 2005, Warren et al. 2006, Latinus et al. 2011). Neuroimaging as well as lesion studies evidenced that voice-sensitive regions are more pronounced in the right hemisphere; for neuroimaging studies see Belin et al. (2000), Belin et al. (2002), von Kriegstein et al. (2003), Formisano et al. (2008), Bonte et al. (2009), Kreifelts et al. (2009); for lesion studies see Assal et al. (1981), Van Lancker and Canter (1982), Van Lancker and Kreiman (1987), Van Lancker et al. (1988), Van Lancker et al. (1989), Neuner and Schweinberger (2000), Lang et al. (2009).

There is neuroimaging evidence that the more anterior regions of the STG/S seem to be involved in voice-identity processing. For example, right anterior STG/S yielded higher blood oxygen level dependent (BOLD) responses during a speaker task than a speech task on the same stimulus input (von Kriegstein et al. 2003, von Kriegstein and Giraud 2004) or when subjects were presented with changing speakers compared to changing syllables (Belin and Zatorre 2003). A particular role

of the right anterior STG/S as well as the middle STG/S in voice-identity processing also has been suggested, because voice stimuli at greater distance from a prototypical voice elicited greater BOLD signal in these regions; for aSTG/S see Andics et al. (2010); for mSTG/S see Latinus et al. (2013). Also, magnetoencephalography (MEG) results support a role of the aSTG/S in voice-identity recognition. There were higher responses in right aSTS during a voice-recognition than during a speech-recognition task, and this amplitude difference correlated positively with voice-recognition accuracies among participants (Schall et al. 2015).

Currently, the evidence for an involvement of the anterior STG/S in voice-identity recognition and identity representations has been largely indirect. And the few studies including more causal measures for the neural underpinnings of voice-identity recognition revealed mixed results (Luzzi et al. 2018). There are two lesion studies on patients with neurodegenerative disease that support a causal role of lesions in the right anterior temporal lobe for voice-identity recognition deficits (Hailstone et al. 2010, Hailstone et al. 2011). However, the anterior temporal lobe was not exclusively associated with impaired voice-identity recognition but also with person-identity recognition deficits by face and name. In contrast, studies on patients with focal brain lesions showed that deficient familiar voice-identity recognition is linked to lesioned structures outside the temporal lobe, i.e., right parietal lobe. Interestingly, lesions in the temporal lobes lead to deficient voice discrimination and concurrent intact familiar voice-identity recognition (Van Lancker et al. 1988, Van Lancker et al. 1989).

Aims of the present study

The present study aimed to use transcranial direct current stimulation (tdcs) on the right anterior STG/S to test the hypothesis that the right anterior STG/S is causally involved in voice-identity recognition in neurotypical participants.

To do so, all participants received anodal, cathodal, and sham tdcs on three days while performing a voice-identity recognition task (i.e., speaker task) and a word recognition task (i.e., speech task). In the following, I will refer to the three stimulation conditions with anodal, cathodal, and sham. Based on the common view that anodal should be facilitating, cathodal inhibiting and sham should not influence the underlying brain area (Nitsche et al. 2008), I hypothesized that voice-identity recognition performance is facilitated by anodal and inhibited by cathodal stimulation. I expected that sham has no effect on task performance. Furthermore, I predicted that the modulation of the anterior STG/S is specific to voice-identity processing and does not occur for the speech-recognition task (von Kriegstein et al. 2003, Formisano et al. 2008, Bonte et al. 2009, Friederici et al. 2010).

Materials and Methods

Ethics statement

The study was approved by the Ethics Committee of the Medical Faculty at the University Leipzig, Germany (AZ 129-11-18042011; see supplementary). All participants provided written informed consent to participate in the study in accordance with the 'Declaration of Helsinki'.

Participants

24 participants (16 female, mean age = 25.25 years, *SD* = 2.87, range = 22-28 years) took part in the study. All were German native speakers and right-handed as assessed with the Edinburgh questionnaire (LQ ≥75; Oldfield, 1971). All participants reported having normal hearing and normal or corrected-to-normal vision. None of them reported a history of neurological or psychiatric disease. All 24 participants fulfilled the inclusion criteria for tdcs application. One of the 24 participants had a retainer and could therefore not participate in the MRI-scan. The participants did not attend any other tdcs study during the period of the experiment. All participants were compensated for their participation.

Experimental Procedure

Stimuli

I took stimuli from an in-house data base. They were high-quality speech stimuli spoken by four male native standard German speakers (age = 23, 27, 22, and 22 years). The speakers were instructed to speak at a normal speech rate with an emotionally neutral intonation. All speakers were unknown to the participants prior to the experiment. The stimulus material consisted of short-stories, five-word sentences, and two-word sentences. The short stories were taken from a creative writing competition (http://www.zeit.de/campus/2009/literaturwettbewerb/junge-stimmen-2009). One story lasted about ten min. The five-word sentences consisted of 100 declarative (e.g., German: “Der Junge trägt einen Koffer.”; english: The boy carries a suitcase.) and 18 five-word interrogative sentences (e.g.,”Trägt der Junge einen Koffer?”, Does the boy carry a suitcase?). One five-word sentence lasted approximately 1.7 sec. The two-word sentences consisted of 240 declarative (e.g.,”Er sagt.”, He says.) and 240 interrogative sentences (e.g.,”Er sagt?”, Does he say?). One two-word sentence lasted approximately 0.7 sec.

All short stories and sentences were recorded from all four speakers in a sound-attenuating chamber using a condenser microphone (Neumann TLM 50, Berlin; Mic-Peramp: Mic-Amp F35, Lake People, Germany; Soundcard: Power Mac G5 Dual 1.8 GHz, Apple Inc., CA, USA; 44.1 kHz sampling rate, and 16 bit resolution) and the software Sound Studio 3 (Felt Tip Inc., NY, USA). Stimuli were post-processed using Audacity (version 1.3.5. beta, http://audacity.sourceforge.net) and Matlab (version 8.1, The MathWorks, Inc., MA, USA), and were normalized for peak amplitude using PRAAT (Boersma and Weenink, 2005).

Experimental Design

The study had a randomized, SHAM-controlled, double-blinded within-subjects design (Figure 1).

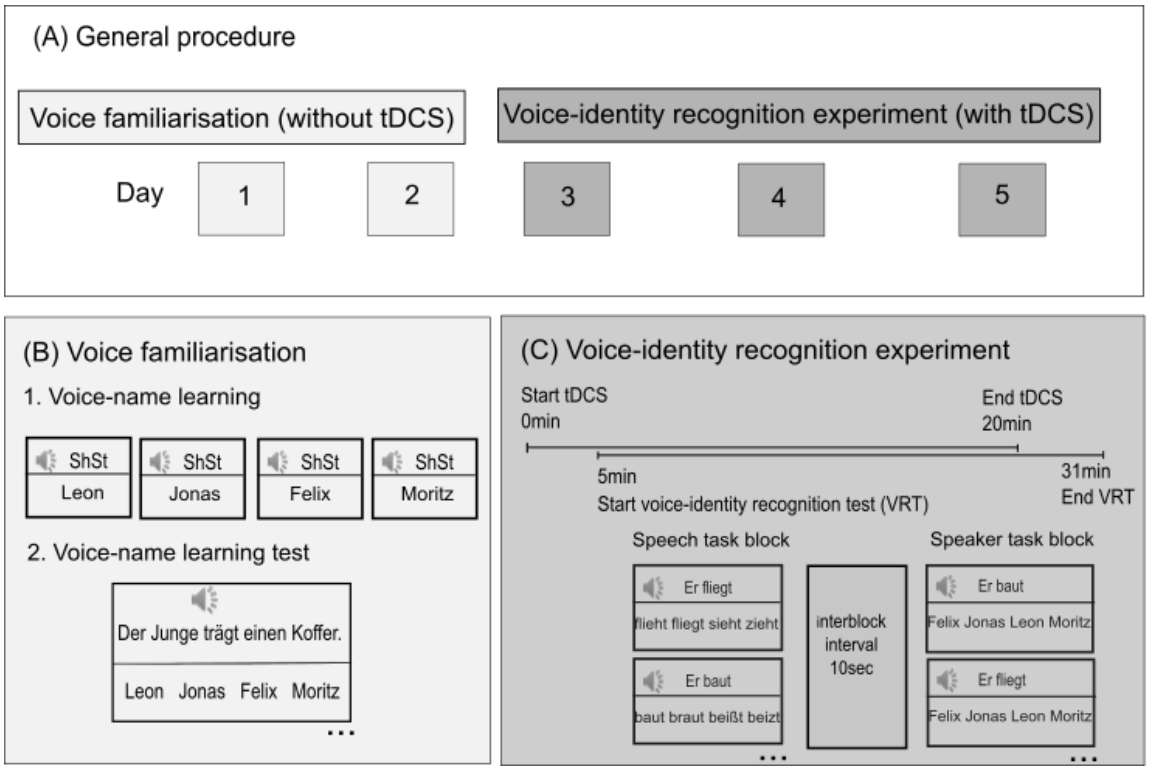

Figure 1 (A)-(C) Experimental Design

(A)The experimental protocol comprised two parts: (i) a voice familiarisation part on two subsequent days; ii) a tdcs experiment testing for voice-identity recognition. Each participant received all three tdcs treatments (i.e., anodal, cathodal, and sham tdcs) on three different days.

(B) The voice-familiarisation included two sessions: (i) a voice-name learning and (ii) a voice-name learning test.

Voice-name learning: During voice learning, participants listened to short stories uttered by each of the four male speakers. For each speaker, the respective name was provided on the screen. [ShSt = Short story]

Voice-name learning test: During the voice-name learning test participants were presented with a target voice (uttering five-word sentences) and were asked to match the correct speaker's name (keys 1-4) to the target voice (i.e.,(1) for Leon, (2) for Jonas, (3) for Felix and (4) for Moritz).

(C) All participants received anodal, cathodal, and sham tdcs to the right aSTS/G.

Direct current was maintained for 20 min and the voice-identity recognition test started after five min of tdcs. In the voice-identity recognition test, participants did a speech task and a speaker task. In total, there were six blocks for each task and each block contained 40 trials. One trial lasted three sec. There was an interblock interval of ten sec.

The study included a voice-familiarisation part without tdcs, in which participants learned to recognise four different speakers by their voice over two days. The voice-familiarisation part was followed by the voice-identity recognition experiment with tdcs including three sessions on different days. For all parts of the study, participants were seated in front of a computer screen, on which the visual information was presented. The auditory stimuli were delivered through headphones (Sennheiser, HD 280 pro, 64Ω, Sennheiser, Wedemark, Germany). For all tasks, participants' responses were recorded via key press on the computer keyboard. I presented the stimuli and recorded the key press responses using Python software (Version 2.7.3, Python Software Foundation; open source license).

Voice familiarization (without tdcs)

The voice familiarisation proceeded over two days, in which participants learned the names and voices of the four speakers (Figure 1B). The familiarisation comprised ca. 80 min total listening time (20 min per speaker) and a total duration of 1.5 to two hours per day. On each day participants first learned the association between a speaker's voice and the corresponding target name (voice-name learning) and were then, subsequently after each learning session, tested on how well they learned the voice-name associations (voice-name test).

Voice-name learning

For the voice-name learning participants listened to short stories spoken by each speaker. At the same time the corresponding speaker's name was presented on the screen.

On the first day of voice familiarization participants conducted three learning sessions. First, participants listened to two short stories; one spoken by speaker 'Leon' (1) and the other by speaker 'Jonas' (2) amounting to 20 min of listening (ten min per story). The second voice-name learning session contained two short stories spoken by the speaker 'Felix' (3) and 'Moritz' (4). The third learning session comprised four short stories spoken by all four speakers presented in the order (1), (2), (3), (4) amounting to 40 min of learning.

On the second day, participants conducted two learning sessions. In each session short stories of all four speakers were presented. The order of speaker presentation was reversed compared to day one (i.e., speaker (4), (3), (2), (1)).

During voice familiarization, each voice-name learning session was followed by a voice-name learning test, in which the learning rates for the respective speakers were tested.

Voice-name learning test

During the voice-name learning test, the learning rate of how well participants associated the name to each respective speaker's voice was assessed. On each trial participants were presented with a sentence spoken by one of the speakers and simultaneously with numbered written names of all four speakers. The auditory material consisted of five-word declarative and interrogative sentences that were all presented in random order. After each sentence presentation participants were asked to indicate the name corresponding to the target speaker's voice by pressing the respective key on the keyboard (i.e., 1, 2, 3, 4).

After a correct trial the next sentence was presented. After an incorrect trial the same trial was repeated until it was completed correctly. There was no time restriction for the response.

The voice-name learning test stopped after ten correct trials in a row after the voice-name learning session, which contained four short stories, and after 15 correct trials in a row after the voice-name learning session, which contained four short stories. If participants failed to correctly respond to ten trials or 15 trials, respectively, in a row, the training went on until 100 trials were completed, irrespective if the trials were correct or not.

Voice-identity recognition experiment (with tdcs)

The voice-identity recognition experiment consisted of (i) a voice-identity recognition test that included a speaker and a speech task and (ii) the tdcs application (Figure 1C). In the speaker task, participants listened to two-word sentences spoken by the previously learned four speakers. Simultaneously to the auditory presentation, participants were presented with the speakers' names (numbered 1-4) on the screen. Participants were asked to indicate the name corresponding to the target speaker's voice by pressing the respective key (1-4).

The speech task was performed on the same auditory stimuli as the speaker task. However, now, after auditory presentation, instead of names, four German verbs were presented on the screen (numbered 1-4). All German verbs were phonologically similar (e.g., "flieht", "fliegt", "sieht", "zieht"; english: "flees-flies-sees-

pulls"). Participants were asked to indicate which written verb matched the verb of the two-word sentence.

In both tasks after three sec the next trial started regardless of any key press. There was no feedback about correct responses provided.

The voice-identity recognition test was arranged in 12 blocks, i.e., six blocks of the speaker task and six blocks of the speech task. Speaker and speech task blocks were presented in alternating order with an inter-block interval of ten sec. The name and word options on the response screen informed participants about the task they had to perform, i.e., speaker or speech task, respectively.

In addition, test instructions, which participants received prior to the experiment, informed participants about the alternating block order. Each block contained 40 trials in a randomised order. The complete voice-identity recognition test lasted 26 min. Participants conducted the voice-identity recognition test on three separate days with a different tdcs application on each day (see section below 'Transcranial direct current stimulation (tdcs)')

Questionnaires

The study comprised three questionnaires (see supplementary; the questionnaires are in German). The first questionnaire had to be completed prior to the tdcs experiment. The participants reported their current mood and well-being, motivation for the experiment, and drug consumption. The second questionnaire was completed after each tdcs session. This questionnaire comprised, again, the mood questionnaire plus questions about their subjective feeling on how well they performed the voice-identity recognition test and about side effects of tdcs (Loo et al. 2010, Brunoni et al. 2011, Kessler et al. 2012, Palm et al. 2013). The third questionnaire was completed after the third day of tdcs application. This questionnaire included questions about potential strategies for the speaker recognition task used in the voice-identity recognition test ('strategy questionnaire').

Transcranial direct current stimulation (tdcs)

Tdcs sessions

On three separate days each participant completed different tdcs sessions, i.e., with anodal, cathodal, and sham tdcs, respectively. This approach is similar to previous studies, which have included both active (i.e., anodal and cathodal) and sham

stimulation (Fregni et al. 2006, Boggio et al. 2008, Loo et al. 2010, Nitsche and Paulus 2011). During each tdcs session, participants performed a voice-identity recognition test. In total, each voice-identity recognition experiment lasted 31 min, including 20 min of tdcs application and 26 min of voice-identity recognition test. The voice-identity recognition test started five min after the tdcs application. Accordingly, there was a phase of tdcs without testing (i.e., five min at the beginning) and a phase of testing without tdcs (i.e., 11 min at the end). This design took advantage of the tdcs aftereffects that occur for up to one hour after the end of a stimulation that had a duration of ten min or longer (Nitsche and Paulus 2001, Liebetanz et al. 2002, Priori 2003, Monte-Silva et al. 2010).

The order of stimulation type was randomized between participants. Since each participant received anodal, cathodal, and sham tdcs, there were six different possibilities of stimulation order (i.e., ACS, ASC, CAS, CSA, SAC, SCA // A=anodal, C=cathodal, S=sham).

Within each participant each of the three sessions was conducted at approximately the same time of day (+/- 1 or 1.5 hours). This allowed testing participants at a similar level of alertness since the time of day is proposed to be an important determinant of the induction of plasticity (Ridding and Ziemann 2010). To avoid potential carry-over effects of the stimulation, an interval of 48 - 72 hours between the tdcs sessions was set (Nitsche et al. 2008).

Tdcs parameters

For the tdcs parameters refer to table 1.

Table1 Tdcs parameters

DC-Stimulator	NeuroConn GmbH, Ilmenau, Germany
Electrode material	Rubber electrodes, conductive paste
Electrode size	active e.: 9 cm² | reference e.: 100 cm²
Electrode form	rectangle
Current strength	.75 mA
Current density	.083 mA/cm² at the active e. .0075 mA/cm² at the reference e.
Duration	20 min for anodal and cathodal | 30 sec for sham | 30 sec fade in and fade out for all conditions

Table1
Displayed are the tdcs parameters used in the current study

TDCS acts through a very low direct current, which is utilized to modulate cortical excitability (Nitsche et al. 2008, Brunoni et al. 2012). It shifts the resting membrane potential without directly triggering action potentials (Radman et al. 2009), other than TMS (Sparing and Mottaghy 2008, Priori et al. 2009).
For tdcs a weak direct current of .74 mA was delivered for 20 min (30 sec for SHAM tdcs) using a battery driven stimulator (DC-STIMULATOR-PLUS, Model-no: 0021, SN: 1367, Power: 1.2W, neuroConn GmbH, Ilmenau, Germany). I used rectangular rubber electrodes with surfaces of (A = 2.5 cm * 3.6 cm = 9 cm²; current density .083 mA/cm²) for the active and (A = 10 * 10 cm = 100 cm²; current density .0075 mA/cm²) for the reference electrode (Nitsche et al. 2007). Current density was within the recommended limit (< .1 mA/cm²) to prevent tissue damage (Federal Institute for Drugs and Medical Devices, Bonn, Germany). The maximum impedance was set to 15 kΩ.

My tdcs parameters were in accordance with the safety guidelines provided by Iyer et al. (2005), Poreisz et al. (2007), Bikson et al. (2009).

The active electrode was placed over the target brain region, the right aSTG/S. The reference electrode was placed over the right shoulder joint (i.e., Musculus deltoideus). Using an extra cephalic reference electrode has the following advantages: It avoids the confounding effects of two electrodes with opposite polarities over the brain (Cogiamanian et al. 2007) and, in addition, the increasing electrode separation leads to an increasing relative amount of current entering the brain (Bikson et al. 2010). Applying tdcs with an extra cephalic reference electrode has been reported as a safe procedure in neurotypical participants previously (Vandermeeren et al. 2010, Im et al. 2012).

The electrodes were covered with highly conductive electrode gel “Ten20 Conductive Paste” (Weaver and Company, CITY info, USA).

The active electrode was fixed using flexible straps to avoid electrode movement. For the fixation of the reference electrode a fabric ribbon was used with a hook and look fastener.

I used disinfectant skin preparation of the stimulated skin areas prior to each stimulation session to reduce resistance and to improve homogeneity of the electric field under the electrode (Nitsche et al. 2008, DaSilva et al. 2011, Kronberg and Bikson 2012). Current was ramped up for 30 sec in the beginning and ramped down for 30 sec at the end of the stimulation block to minimize discomfort.

Blinding

Participants and the experiment instructor were blinded regarding the tdcs application type (i.e., whether anodal, cathodal, or sham was delivered) to prevent biased responses (Boutron et al. 2007, Brunoni et al. 2011). The double blinding (i.e., of participants and experiment instructor) was accomplished by the following procedure: In addition to the experiment instructor there was one person at the beginning of the experiment to operate the tdcs device (i.e., tdcs operator). The function of the tdcs operator was to start the tdcs devise by setting the respective tdcs application (i.e., anodal, cathodal, sham). This was done in a way that the stimulation type was blind to the experiment instructor and participants during the complete experiment time: (i) The devise sound was switched off for the sham tdcs session. By default settings the stimulation end of the tdcs-stimulator is indicated by

a device sound i.e., after 30 sec for sham and after 20 min for anodal, cathodal tdcs. For anodal and cathodal tdcs the sound was not switched off for security reasons as the signal also indicates a potential increment of the impedance exceeding the manual set threshold 15 kΩ. Though, in the current study the impedance did not exceed this threshold. (ii) Irrespective of the length of stimulation (i.e., 30 sec for sham and 20 min for anodal, cathodal), the experiment instructor pressed the on-off button after 20 min making the procedures between all three tdcs conditions as similar as possible (Boutron et al. 2007, Brunoni et al. 2011). (iii) After setting the stimulation type, the tdcs operator covered the device display to ensure that the experiment instructor and participants could not see the displayed stimulation type (Poreisz et al. 2007).

Description of MRI scanning parameters

Individual structural magnet resonance imaging (sMRI) scans were acquired at three different 3T MRI scanners (in order to, later, localize the target brain region for the placement of the electrode during tdcs; see “Localisation of target brain region” below). Eight participants were scanned on a 3T Siemens MAGNETOM TIM TRIO Scanner (Siemens AG, Berlin and Munich, Germany). Four of the participants had the following parameters (TI = 650 ms; TR = 1300 ms; TE = 3.46 ms; alpha = 10°; image matrix = 256 x 240; FOV = 256 mm x 240 mm; voxel size = 1x1x1), another three participants with (TI = 900 ms; TR = 2300 ms; TE = 2.96 ms; alpha = 9°; image matrix = 256 x 240; FOV = 256 mm x 240 mm; voxel size = 1x1x1), and another one (TI = 650 ms; TR = 1300 ms; TE = 2.23 ms; alpha = 10°; image matrix = 256 x 240; FOV = 256 mm x 240 mm; voxel size = 1x1x1). There were 13 participants that were scanned on a 3T Siemens MAGNETOM PRISMA Scanner (Siemens AG, Berlin and Munich, Germany) with nine of them having the following parameters (TI = 650 ms; TR = 1300 ms; TE = 3.5 ms; alpha = 8°; image matrix = 256 x 240; FOV = 256 mm x 240 mm; voxel size = 1x1x1) and one participant with the following parameters (TI = 900 ms; TR = 2300 ms; TE = 2.98 ms; alpha = 9°; image matrix = 256 x 240; FOV = 256 mm x 240 mm; voxel size = 1x1x1). Two participants were scanned on a 3T Siemens MAGNETOM VERIO Scanner (Siemens AG, Berlin and Munich, Germany) with the following parameters ((TI = 900 ms; TR = 2300 ms; TE = 2.98 ms; alpha = 9°; image matrix = 256 x 240; FOV = 256 mm x 240 mm; voxel size = 1x1x1).

Localisation of target brain region

To locate the region of interest I used an MNI coordinate that was found to be sensitive to voice-identity recognition in an earlier functional MRI study (von Kriegstein and Giraud, 2004). The coordinate was located in the right anterior STG/S [x/y/z (51/18/-15) MNI space] and represented the statistical maximum for a contrast between a task, in which participants had to recognize a target speaker's voice, in comparison to recognize a spoken word. The peak coordinate is close to other coordinates reported to be responsive to voice-identity processing (see Figure 2).

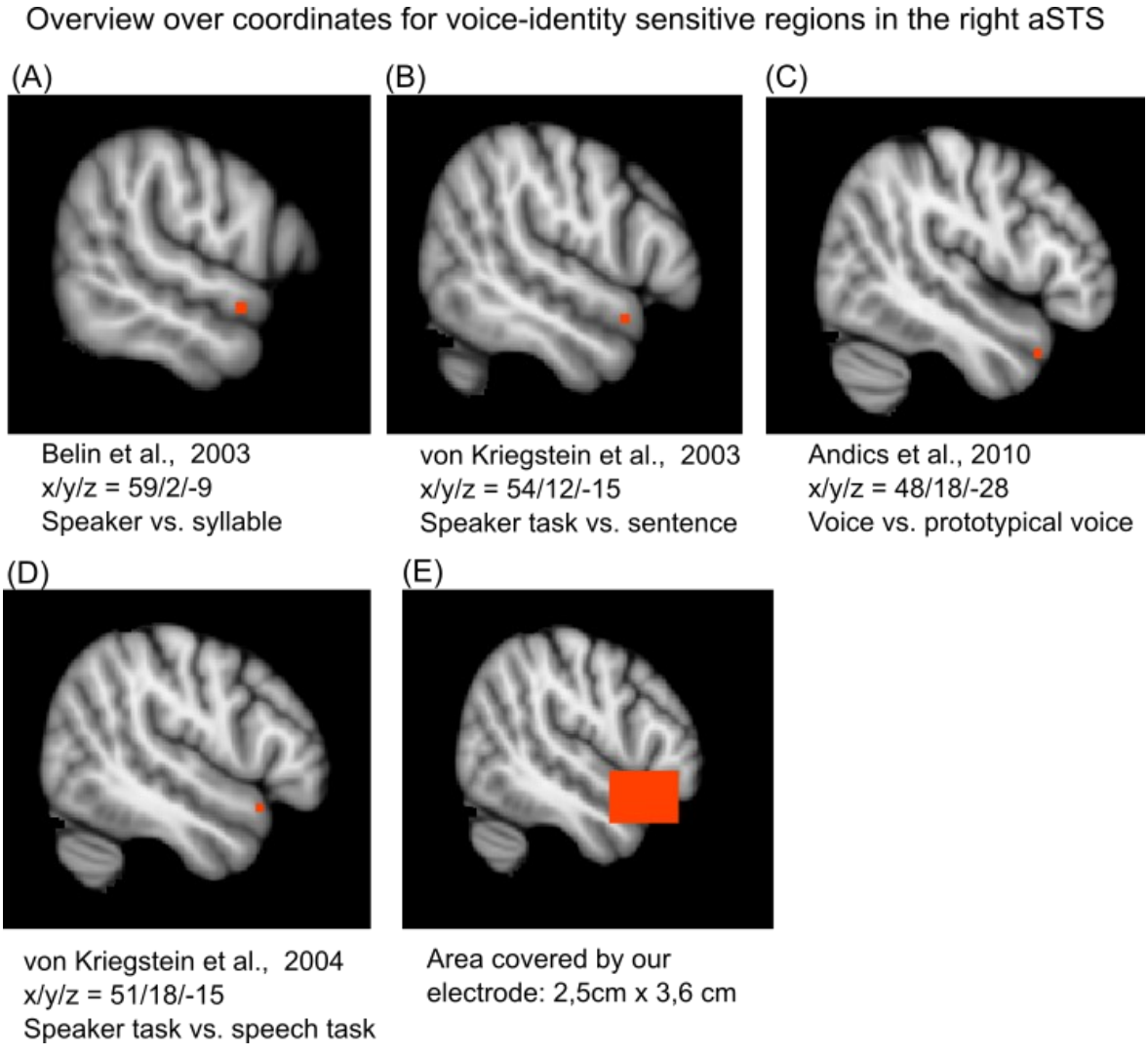

Figure 2 Overview over coordinates for voice-identity sensitive regions in the right STS (A)- (D): Displayed are four different neuroimaging studies that found voice-identity sensitive regions. The regions are indicated via red spots. The first line under a picture indicates the study, the second line the MNI-coordinate of the voice-identity sensitive region for the task that is displayed in the third line.

(E): The red surface illustrates the region covered by the active electrode during tdcs.

To locate the coordinate in each participant, I used the previously acquired individual sMRIs (n = 23). Because one participant had an exclusion criterion for MRI (e.g., a retainer), I used a sMRI scan of another participant that had a similar head anatomy based on visual inspection. The scans were either taken from the in-house MRI-database, if available, or were acquired preceding the tdcs experiment.
Data sets were transferred in digital imaging and communications in medicine (DICOM) format to a G3 Power Macintosh workstation (Apple Computer Inc., Cupertino, California, United States). I used Brainsight software (version 1.7.8, Rogue Research, Montreal, Quebec, Canada) to create and visualise three-dimensional cortical surfaces.

For each participant the individual right anterior STG/S was marked on the scalp for defining the position of the active electrode. This was done using image-guided frameless stereotaxic consisting of a Polaris position sensor (Northern Digital Inc., Waterloo, Ontario, Canada), a tracker attached to the participant's head, and a pointer tool to define the participant's position in space.

Data analysis

I used SPSS Statistics 22 (IBM SPSS Statistics, Armonk, New York, United States) to perform a Linear mixed model analysis to compare voice recognition (i.e., accuracy and reaction time measures of the participants' responses in the speaker and speech task) under the influence of anodal, cathodal, and sham tdcs. I modelled the fixed effects Task (i.e., speaker and speech task), Treatment (i.e., anodal, cathodal, sham), Day (Day1, Day2, Day3), and all multivariate variables (i.e., Task*Treatment, Task*DAY, Treatment*DAY, Task*Treatment*DAY). As random effects I had intercepts for subjects.

For normality testing: I examined the assumption of normality qualitatively a posteriori and looked at the empirical distribution of the residuals.

For all statistical tests the level of significance was defined at $\alpha = .05$.

Results

Accuracy

The accuracy scores in percent correct (%) averaged over the three sessions are plotted in Figure 3.

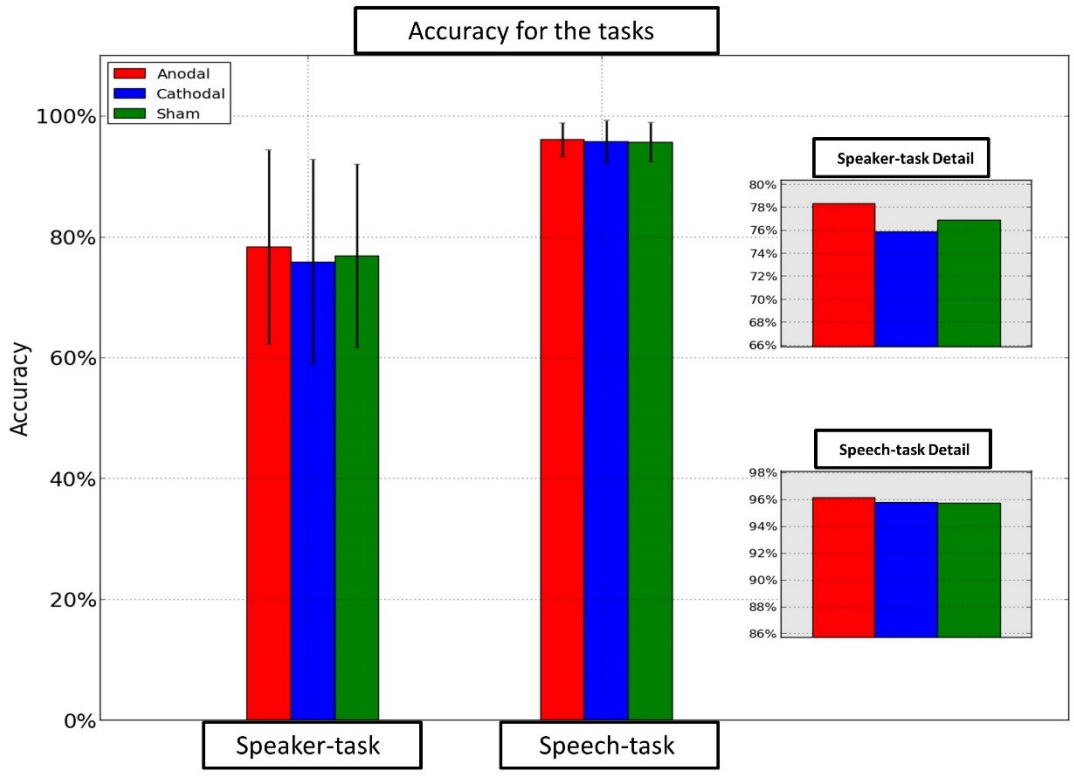

Figure 3 Accuracy for the tasks
Displayed are the mean correct responses for the speech task and for the speaker task.

The Linear Mixed Model analysis revealed a significant main effect of Task ($F_{(1,103)} = 192.3$, $p = .000$) and a significant three way interaction between the factors Treatment, Task and Day ($F_{(4,103)} = 4.99$, $p = .001$).

Contrary to my hypothesis, there was no significant interaction of Treatment and Task. Also the main effects of Treatment, Day, and the interactions between Treatment and Day and Task and Day were not significant.
To investigate the cause of the significant three way interaction I split the data by Day. Table 2 and Figure 4 show the accuracy scores for each day separately.

Table 2 Accuracy scores for each day separately

Accuracy per day [Mean (*SD*) %]	**Speaker task**	**Speech task**
Day one Total	**73.5 (.15)**	**95.0 (.03)**
Anodal	67.9 (.17)	96.1 (.02)
Cathodal	70.3(.16)	94.4 (.02)
Sham	79.6 (.12)	94.6 (.03)
Day two Total	**78.6 (.16)**	**96.0 (.03)**
Anodal	73.5 (.16)	94.4 (.04)
Cathodal	84.9 (.12)	97.5 (.02)
Sham	75.0 (.22)	95.8 (.04)
Day three Total	**79.0 (.17)**	**96.6 (.03)**
Anodal	90.7 (.05)	97.6 (.01)
Cathodal	68.6 (.21)	95.6 (.06)
Sham	74.9 (.16)	97.1 (.02)

Table 2

Displayed are the behavioural results in mean percent correct for accuracy for the different types of stimulation (anodal, cathodal, sham) separately for day and task. The numbers in brackets indicate the standard deviation (*SD*).

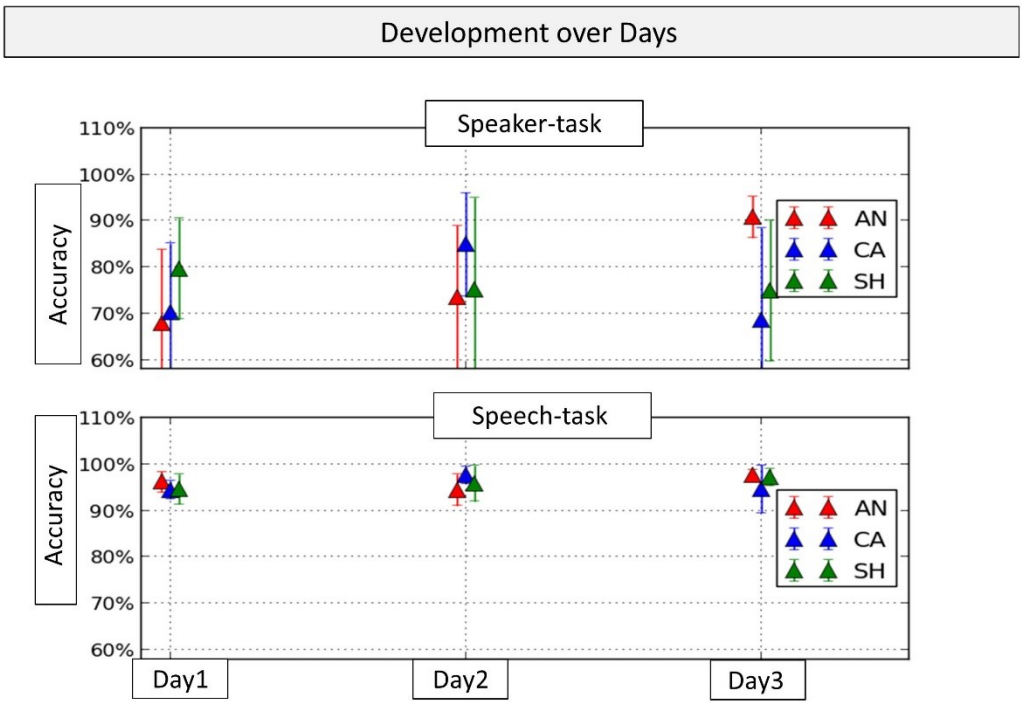

Figure 4 Development over days

Displayed are the mean accuracy results for the speaker task and speech task (the displayed error bars represent +/- one standard deviation (*SD*))

On day three there was a significant main effect of Treatment ($F_{(2, 21)} = 4.74$, $p = .020$) and a significant interaction between the factors Treatment and Task ($F_{(2, 21)} = 4.36$, $p = .026$). For the other days, these effects were not significant. The significant main effect of Task was present on all three days (all $p < .001$).

To investigate the cause of the significant Treatment and Task interaction at day three I split the day three data by Task and did a pairwise comparison between the stimulation types (Table 3).

Table 3 Speaker and Speech Task separated on Day three

	Speaker	Speech
AN vs. CA	**.008**	.074
AN vs. SH	**.042**	.751
CA vs. SH	.430	.141
Treatment	**.021**	.168

Table 3

Speaker and Speech Task separated on **Day three**. The stimulation types were compared with each other. Displayed are the p-values of the pairwise comparisons of anodal, cathodal, and sham, and the fixed effects for the factor Treatment. The significant p-values are printed in bold print. AN=anodal tdcs; CA=cathodal tdcs; SH= sham tdcs

In line with my hypothesis, performance on the speaker task was significantly higher for anodal compared to cathodal (p = .008, difference of the mean: .221, confidence interval: .06 - .38, Standard error: .078) and sham (p = .042, difference of the mean: .158, confidence interval: .006 - .31, Standard error: .073) on day three. Conversely, for the speech task no significant effects were found.

Reaction time

The mixed model analysis of reaction time (for the behavioral results refer to table 4) yielded a significant main effect of Task ($F_{(1,103)}$ = 81 , p = .000) and Day ($F_{(2,104)}$ = 13.354, p = .000) indicating that the reaction times were faster for the speech than the speaker task and that reaction time decreased over the three experimental sessions. There were no further significant effects. This suggested that the significant effects found within the accuracy data analysis were not introduced due to an accuracy-reaction time trade off.

Table 4 Mean reaction times (RT)

RT per day [Mean (*SD*) %]	**Speaker task**	**Speech task**
Day one		
Anodal	1645 (201)	1782 (100)
Cathodal	1621(166)	1755 (105)
Sham	1614 (213)	1846 (202)
Day two		
Anodal	1547 (238)	1736 (142)
Cathodal	1507 (124)	1657 (118)
Sham	1608 (198)	1712 (126)
Day three		
Anodal	1499 (178)	1680 (180)
Cathodal	1542 (278)	1794 (168)
Sham	1494 (195)	1599 (136)

Table 4

Displayed are the mean reaction times (RT) for responding to the required tasks, separated for the different types of stimulation (anodal, cathodal, sham) and for day and task. RT are displayed in millisec, the numbers in brackets indicate the standard deviation (*SD*).

Evaluation of the questionnaires

Side effects

All participants tolerated the stimulation well. Most of them experienced the expected tingling sensation on the skin during the ramp-up phase of tdcs. The side effects were similar across all three stimulation conditions. For a detailed breakdown of stimulation type and sensation refer to table 5.

Table 5 Side effects that occurred during and after each tdcs session

Side effects	**Total (out of 72 sessions)**	**anodal**	**cathodal**	**sham**
Tingling	69	1x no tingling	-	2x no tingling
Skin redness	15	9	6	-
Headache	8	2	3	3
Slight fatigue	6	4	1	1
Afterimages	1	1	-	-

Table 5:
The table displays the side effects that occurred during and after each tdcs session. Effects were recorded via a questionnaire (see supplementary).

Subjective performance level evaluation

The participants were informed about the hypothesized effect of anodal, cathodal, and sham tdcs and that within each session they received another stimulation type. To assess whether the blinding worked for the participants, I asked them after each tdcs session to guess whether their performance had changed due to the respective tdcs application. Using a non-parametric binominal test, I tested for unknown probabilities, i.e., whether there was a significant deviation from 33% in guessing (i.e., chance level). In neither of the stimulations there was a significant difference from 33% of “guessing rate” (p = .58).

Discussion

The aim of the current study was to provide causal evidence for the involvement of the right anterior STG/S in voice-identity recognition.
In accordance with my hypothesis, anodal tdcs to the right anterior STG/S significantly increased voice-identity recognition compared to sham and cathodal tdcs. This was, however, only evident on day three of stimulation. In contrast, a speech task on the same stimulus material was not affected by any of the tdcs conditions.

The results are in line with current neuroimaging studies that ascribe voice-identity recognition to the right anterior STG/S (Belin and Zatorre 2003, von Kriegstein et al. 2003, von Kriegstein and Giraud 2004, Andics et al. 2010, Blank et al. 2011, Blank et al. 2015, Schall et al. 2015). I make a fundamental advance in comparison to these neuroimaging studies as I am the first to provide direct evidence of a causal role of the anterior STG/S in voice-identity recognition in neurotypical participants.
The evidence for a causal role of the anterior STG/S in voice-identity recognition has so far been scarce.

One previous brain stimulation study has investigated the link between right middle temporal voice area (TVA), detected individually for each participant, and voice detection ability while listening to vocal compared to von-vocal sounds (for information about vocal vs. non-vocal sounds see: Belin et al. (2000)). The ability of discriminating voices from non-voice sounds using transcranial magnetic stimulation (TMS) was significantly impaired when TMS was targeted at the right middle TVA (Bestelmeyer et al. 2011). They conclude that it is likely that right TVA is causally related to voice cognition and that the right TVA could subserve higher auditory functions.

The stimulation effect on voice, but not on word recognition, integrates well with the assumption of a relative independence of these two processes. This assumption was based on neuroimaging as well as lesion studies. There is a wealth of evidence that linguistic material is preferentially processed in the left hemisphere (Hickok and Poeppel 2007, Friederici et al. 2010).

Furthermore, this seems largely independent from processing of voice-identity (Belin and Zatorre 2003, von Kriegstein et al. 2003, Formisano et al. 2008, Bonte et al. 2009, Schall and von Kriegstein 2014). Also, results of patient studies suggested a dissociation between voice-identity recognition difficulties and aphasic symptoms (Assal et al. 1976, Assal et al. 1981, Lang et al. 2009). The finding of an independent effect of stimulation on the speaker, but not the speech task, complements these findings and emphasises the preference particularly of the right anterior STG/S in the representation of voice-identity.

It was surprising that the expected tdcs effect on voice-identity recognition only occurred at day three of testing. I can only speculate about the possible reasons for this. When applying tdcs, the anodal treatment is assumed to enhance and cathodal to down regulate cortical excitability (Nitsche and Paulus 2000, Stagg et al. 2009). Especially for tdcs studies on cognitive functions it has been shown that anodal has a probability of .81 of enhancing and cathodal a probability of .48 of down-regulating cortical excitability (Jacobson et al. 2012). Thus, the null-effects at day one and two could be due to the variable nature of tdcs effects. A second possibility is that the anterior STG/S is only critically involved in voice-identity recognition if the voices have been learned over a longer time period. However, there is currently no evidence for such an interpretation as all fMRI-studies that showed BOLD responses in anterior STG/S involved either no training (Belin and Zatorre 2003) or a relatively short training before the sessions for the unfamiliar voices, the familiar voices were the voices of working colleagues (von Kriegstein and Giraud 2004) and a short training before the sessions consisting of the presenting of 36 sentences per voice (von Kriegstein et al. 2003).

The active electrode was well placed above the right anterior STG/S individually for each participant. However, the spatial resolution of tdcs within the human brain is largely unknown and has low spatial precision (Nitsche et al. 2007, Miranda et al. 2009). Because of the electrode size in the present study (A = 2.5 * 3.6 cm = 9 cm^2), it covered not only anterior STG/S but also parts of frontal regions. Parts of the frontal cortex are found to be voice sensitive, named frontal voice areas or “the extended system of the voice perception” and are part of the “voice perception network” showing functional connectivity to TVAs during voice perception (Aglieri et al. 2018). Still, there exists no consensus to what extent they

are involved in voice identity recognition and furthermore, to what degree the familiarity of a voice increases or decreases BOLD responses (Zaske et al. 2017).

There are two studies that have found the right IFG being involved in the processing of speaker-identity, independently of verbal information (Latinus et al. 2011, Zaske et al. 2017). However, all BOLD responses reported in Latinus et al. (2011) underlying the perception of learned identities (i.e., [(Between and Within) > Same] in the second session of scanning) are located more superior to the space covered by the electrode. They report one BOLD response in the right IFC/insula [x/y/z (33/27/0) MNI space], which could have been affected in my study since the coordinate is just 2 mm away from the upper frame of the electrode. However, the BOLD response in this region occurred during the first session of scanning where identity changes were linked to physical changes in the perceived stimuli and they were not yet associated with any learned identities.

Looking at the coordinates (i.e., [x/y/z (52/20/26) MNI space]) reported by Zaske et al. (2017), who discuss the right IFC in being involved in learned voice recognition (i.e., reduced activation in right IFG for voices correctly classified as “old” compared to “new”) it is still unlikely that my electrode affected this region since it is 2.6 cm away from the upper frame of the electrode.

Furthermore, it is unlikely that I stimulated the region offered in the Meta analysis by Blank et al. (2014) who implement right inferior frontal gyrus (i.e., [x/y/z (41/25/21) MNI space]) in learned familiar person-identity recognition.

So taken together, and noting, that a direct comparison between the studies is limited due to different grades of voice familiarity (i.e., different voice learning paradigms) and recognition tasks (i.e., discrimination tasks and recognition tasks), it is unlikely that regions in frontal cortices led to the effect in the present study.

Models of voice-identity recognition assume several stages of processing, i.e., a stage of basic perceptual analysis, a stage were the voice is recognised as familiar, and a stage were association is made to semantic and name information about the person (Ellis et al. 1997, Neuner and Schweinberger 2000, Belin et al. 2004, Roswandowitz et al. 2018). The anterior STG/S has been shown to be responsive to voice-identity processing even if no name of the person was known and the task was passive listening or matching of a previously heard voice to a target voice (Belin

and Zatorre 2003, von Kriegstein et al. 2003, von Kriegstein and Giraud 2004, Andics et al. 2010). In contrast to the more posterior STG/S regions, the anterior STG/S does not seem to be involved in perceptual processing of the voice (von Kriegstein et al. 2003, von Kriegstein and Giraud 2004). It is therefore conceivable that voice-identity processing has been facilitated at the stage where a voice is recognized as familiar. However, the region that responds to voices even if they have not been paired with the name is in very close proximity to regions that have been implied in multimodal person identity recognition; for review see Gainotti (2011), Blank et al. (2014). Because of the inherently low spatial resolution of tdcs I cannot exclude that I additionally stimulated this anterior temporal lobe region. This anterior temporal lobe region is for example more responsive to the matching of names or faces to voices in contrast to matching brand names of mobiles or pictures of mobiles to a mobile ring tone (von Kriegstein and Giraud 2006). Furthermore, BOLD responses in this area positively correlate with the speed of name retrieval when recognizing voice-identity (von Kriegstein and Giraud 2006).
A tdcs study with anodal tdcs to the right and left anterior temporal lobe (T3/T4 electrode location following the international 10-20 system) is congruent with these fMRI findings. Anodal tdcs to the right anterior temporal lobe significantly improved naming of famous people's faces if they had difficulties retrieving the name for the face, but not for places (Ross et al. 2010, Ross et al. 2011).

The question remains open at what stage I modulated voice-identity recognition in the present study.

Conclusion

In conclusion, my findings provide causal evidence for the involvement of the right anterior STG/S in the perception of recently-familiarized (Maguinness et al. 2018) voice identity. This strengthens the currently discussed role of the anterior STG/S in identity representations of human voices in the brain (Blank et al. 2014, Roswandowitz et al. 2018).

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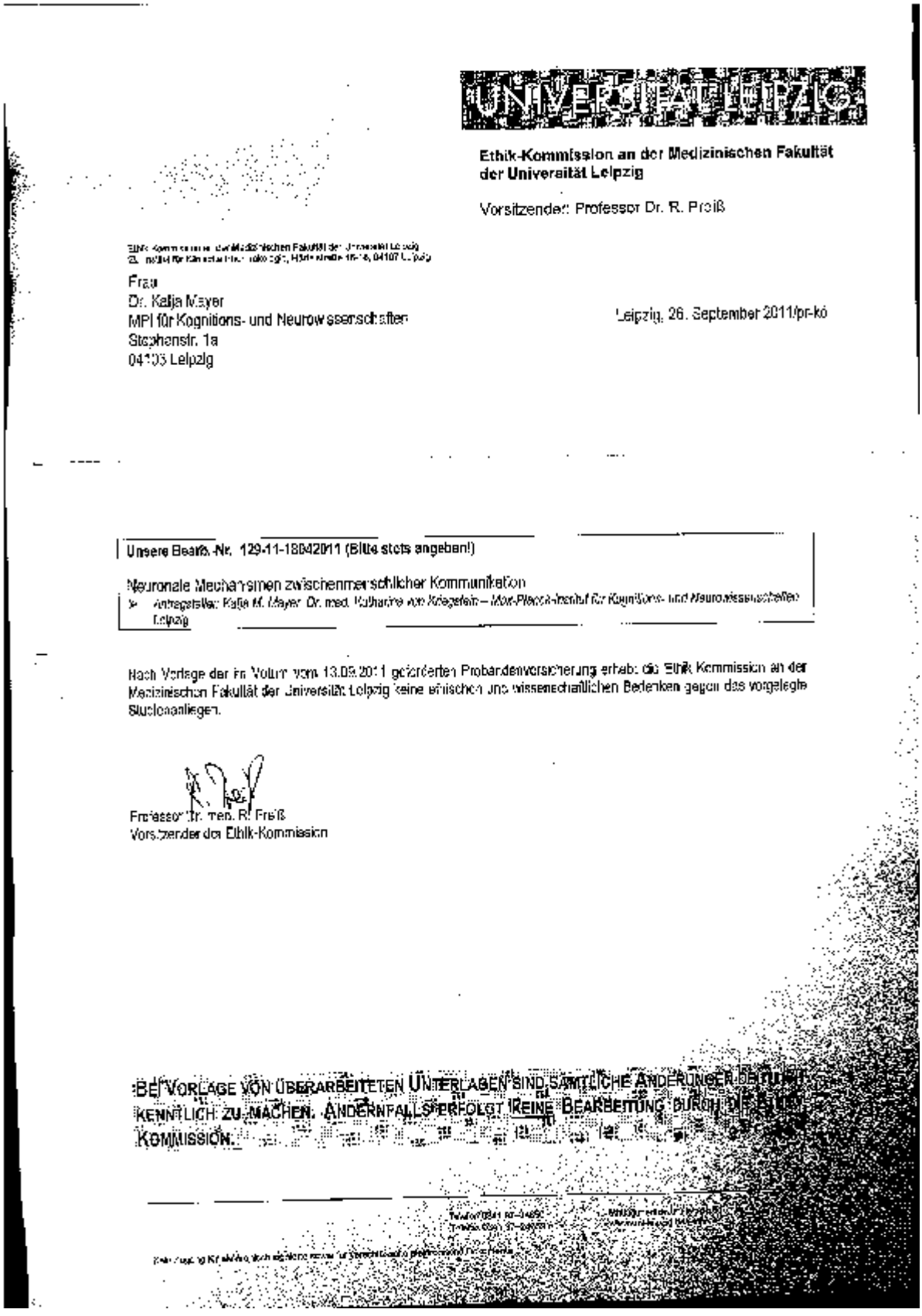
Supplementary

Ethics statement



UNIVERSITÄT LEIPZIG

Ethik-Kommission an der Medizinischen Fakultät der Universität Leipzig

Vorsitzender: Professor Dr. R. Preiß

Ethik-Kommission der Medizinischen Fakultät der Universität Leipzig
c/o Institut für Klinische Pharmakologie, Härtelstraße 16-18, 04107 Leipzig

Frau
Dr. Katja Mayer
MPI für Kognitions- und Neurowissenschaften
Stephanstr. 1a
04103 Leipzig

Leipzig, 26. September 2011/pr-kö

Unsere Beschl.-Nr. 129-11-18042011 (Bitte stets angeben!)

Neuronale Mechanismen zwischenmenschlicher Kommunikation
Antragsteller: Katja M. Mayer, Dr. med. Katharina von Kriegstein – Max-Planck-Institut für Kognitions- und Neurowissenschaften Leipzig

Nach Vorlage der im Votum vom 13.09.2011 geforderten Probandenversicherung erhebt die Ethik-Kommission an der Medizinischen Fakultät der Universität Leipzig keine ethischen und wissenschaftlichen Bedenken gegen das vorgelegte Studienanliegen.

Professor Dr. med. R. Preiß
Vorsitzender der Ethik-Kommission

BEI VORLAGE VON ÜBERARBEITETEN UNTERLAGEN SIND SÄMTLICHE ÄNDERUNGEN DEUTLICH KENNTLICH ZU MACHEN. ANDERNFALLS ERFOLGT KEINE BEARBEITUNG DURCH DIE ETHIK-KOMMISSION.

Evaluation of the questionnaires: Mood

All participants had relatively high ratings on the two mood questionnaires (see Table 6a-c). There were no significant differences in the questionnaire items depending on the type of stimulation or day.

Table 6a-c Contemporary general state of health before and after the tdcs experiment

Table 6a

Day 1	**anodal**		**cathodal**		**sham**	
	before	after	before	after	before	after
well being	7.57	7.71	8	8.14	8.50	7.90
fitness	8	7.71	8.14	7.43	7.80	7.10
motivation	8.43	8.14	7.29	6.57	8.40	7.50
concentration	7.86	6.86	8	7	8.10	6.90
happiness	8.43	8.43	8.43	7.86	8.60	8.50

Table 6b

Day 2	**anodal**		**cathodal**		**sham**	
	before	after	before	after	before	after
well being	8.25	7.75	7.9	7.7	8.17	8.17
fitness	7.75	7.25	7.9	7.1	7.83	7.67
motivation	7.25	7	8	7.4	7.92	7.42
concentration	7.88	6.75	7.6	6.6	7.5	6.83
happiness	8	7.75	7.9	8.1	8.33	8.5

Table 6c

Day 3	**anodal**		**cathodal**		**sham**	
	before	after	before	after	before	after
well being	8.56	8.11	7.86	7.43	8	8
fitness	8.44	7.78	8.00	7.43	7.38	8
motivation	8.44	7.56	8.43	7.86	7.5	7.75
concentration	8.11	7.67	7.71	7.14	7.63	7.38
happiness	8.33	8.22	8.57	8.57	7.88	7.88

Table 6a-c

Contemporary general state of health before and after the tdcs experiment (0-10: 0= not well; 10= very good). Evaluation of the participants' general state of health separated by day and stimulation type. 'Before' refers to the time before the experiment started and 'after' refers to the time after the experiment has been completed.

Table 7 Strategies for speaker recognition

Strategies	
Voice character: how high, deep, bright, clear a voice sounded)	12
Imagination of a person to whom the voice could belong	4
nasality	4
A friend with a similar voice	3
Throatiness	3
Imagination of faces	2
Dialect	2
Similarity to a pop musician/movie star	3
Sympathy of the person? Voice?	1
How male the voices sounded	1

Table 7

Displays the strategies for speaker recognition amongst the participants. The numbers indicate the numbers of participants who used the kind of strategy

Table 8 Difficulty of speaker recognition

Name	**%**
Leon	83.3
Jonas	20.83
Felix	12.5
Moritz	Not mentioned

Table 8

The table displays how many participants found it easiest to recognize a specific speaker. In comparison to the table hereafter in brackets the statistics for correct speaker recognition, in percent: (Leon: 91.7, Jonas: 73.2, Felix: 73.1, Moritz: 66.4)

Questionnaires

Fragebogen VOR der tdcs Testung

Wie ist Ihr heutiger Allgemeinzustand?

Ich fühle mich wohl (10) ----------(5) ---------- unwohl (0)

Ich fühle mich fit (10) ----------(5) ---------- müde (0)

Ich bin motiviert (10) ----------(5) ---------- unmotiviert (0)

Ich bin konzentriert (10)----------(5) ---------- unkonzentriert (0)

Ich bin gut gelaunt (10) ----------(5) ---------- genervt/gereizt/ schlecht gelaunt (0)

Haben Sie in den letzten Nächten ausreichend geschlafen?

Leiden Sie derzeit an Kopfschmerzen? / an anderen Schmerzen?

Hatten Sie in der letzten Zeit Kopfschmerzen/Migräne?

Haben Sie in den vergangen Tagen Alkohol/andere Drogen eingenommen?

Wenn ja, welche und wie viele?

Für Frauen: Besteht die Möglichkeit einer **Schwangerschaft**?

Leiden Sie im Moment an einer Allergie? Atemwege/Haut

Wenn ja, an welchen:

Wie lange lagen Sie in den letzten Tagen in der Sonne?

Wie viel Sport haben Sie in den letzten Tagen getrieben?

Hatten Sie seit der letzten tdcs Anwendung Operationen/Kopfverletzungen?

Hat sich irgendetwas anderes in Ihrem Gesundheitszustand geändert seit der letzten tdcs Anwendung?

Nehmen Sie derzeit an anderen Studien teil? Wenn ja, an welchen?

Fragebogen NACH der tdcs-Testung

Zum Befinden:

Ich fühle mich wohl (10) ----------(5) ---------- unwohl (0)

Ich fühle mich fit (10) ---------- (5) ---------- müde (0)

Ich bin motiviert (10) ----------(5) ---------- unmotiviert (0)

Ich bin konzentriert (10) ----------(5) ---------- unkonzentriert (0)

Ich bin gut gelaunt (10) ----------(5) ---------- ich bin genervt/gereizt/ schlecht gelaunt (0)

Bitte geben Sie auf einer Skala von 0-10 (0=nichts gespürt; 10= stark gespürt) an, ob Sie folgende Wahrnehmungen WÄHREND und/oder NACH der tdcs Anwendung hatten

	WÄHREND	DANACH
Kribbeln (Ort)		
Jucken (Ort)		
Brennen (Ort)		
Schmerz (Ort)		

Kopfschmerz (Ort)

Übelkeit

Lichtblitze

Hatten Sie weitere Wahrnehmungen/Empfindungen?

Was vermuten Sie? Hatten Sie eine **Verbesserung**/**Verschlechterung**/**keine Veränderung** der Aufgabenausführung durch die Anwendung von tdcs?

Befragung zusätzlich nach der dritten Testung („Strategy-Questionnaire“):

Hatten Sie eine Strategie, um die Sprecher wieder zu erkennen? Wenn ja, welche?

Konnten Sie einen Sprecher besonders gut erkennen? Wenn ja, welchen und woran?

Finden Sie, dass die Sprecher Hochdeutsch gesprochen haben? Wenn NEIN: Welcher Sprecher hatte einen Dialekt; und können Sie sagen, welchen Dialekt?

Ist Ihnen einer der beiden Blöcke leichter gefallen? Wenn ja, welcher?

Wie würden Sie das Experiment insgesamt einschätzen? 0= leicht; 6=sehr schwer

Haben Sie sonstige Anmerkungen?

Tdcs Fragebogen

Mit den folgenden Fragen wollen wir mögliche Risikofaktoren der transkraniellen Gleichstromstimulation (tdcs) ausschließen. Sie dienen Ihrer persönlichen Sicherheit während der tdcs Experimente. Bitte antworten Sie nach bestem Wissen und fragen Sie uns jederzeit bei Unklarheiten.

Haben Sie einen Herzschrittmacher, eine Insulinpumpe, einen Shunt

(Hirnwasserdrainage) oder Innenohrimplantat? Ja nein

Haben Sie Metallclips nach Gefäßoperationen oder künstliche Herzklappen?

Ja nein

Haben Sie Gelenkprothesen aus Metall? Ja nein

Haben Sie Metallplatten, -schrauben, -nägel nach Knochenverletzungen? Ja nein

Wurden Sie innerhalb der letzten zwei Monate operiert? Ja nein

Wenn ja, woran?

Haben Sie Herzrhythmusstörungen? Ja nein

Haben Sie Hörprobleme bzw. leiden Sie an Tinnitus? Ja nein

Ist bei Ihnen ein Anfallsleiden (Epilepsie) bekannt? Ja nein

Hatten Sie in der Kindheit jemals einen Fieberkrampf erlitten? Ja nein

Ist in Ihrer Familie eine Epilepsie bekannt? Ja nein

Ist jemals eine unklare Bewusstlosigkeit aufgetreten? Ja nein

Sind bei Ihnen andere neurologische oder psychiatrische Erkrankungen bekannt? Ja nein

(z.B. Multiple Sklerose, ADHS, Schizophrenie, Depression)

Wenn ja, welche?

Hatten Sie jemals behandlungsbedürftige Kopfverletzungen? Ja nein

Hatten Sie jemals behandlungsbedürftige Kopfschmerzen? Ja nein

Leiden Sie regelmäßig an Kopfschmerzen oder Migräne? Ja nein

Leiden Sie an Schlafstörungen? Ja nein

Besteht eine regelmäßige Alkohol- oder andere Drogeneinnahme? Ja nein

(z.B. Psychoaktive Substanzen)

Leiden Sie an einer chronischen Krankheit (Asthma, Bluthochdruck, Diabetes)

Ja nein

Wenn ja welche?

Sind Allergien bekannt? Ja nein

Wenn ja, welche?

Sind Hauterkrankungen bekannt? Ja nein

Nehmen Sie regelmäßig Medikamente (z.B. Schmerzmittel, Antidepressiva, Antipsychotika: z.B. Clozapine, verschreibungspflichtige Stimulanzien)? Ja nein

Wenn ja, welche(s)?

Besteht die Möglichkeit einer Schwangerschaft? Ja nein

Frau/Herr _____ hat mit mir heute anhand der Hinweise dieses Informationsblattes ein Aufklärungsgespräch geführt, in dem ich alle mich interessierenden Fragen stellen konnte.

1 Ich habe keine weiteren Fragen und benötige keine zusätzliche Bedenkzeit.
2 Ich versichere, dass meine Angaben vollständig und richtig sind.
3 Bei möglichen Folgeuntersuchungen informiere ich Sie unaufgefordert über jede Änderung bezüglich der o.g. Angaben sowie über Änderungen meines Gesundheitszustandes.

Illustration Directory

All figures were created by my own.

List of Tables

All tables were created by my own.

Honorary Declaration (Ehrenwörtliche Erklärung)

Hiermit erkläre ich, dass mir die Promotionsordnung der Medizinischen Fakultät der Friedrich-Schiller-Universität bekannt ist,

ich die Dissertation selbst angefertigt habe und alle von mir benutzten Hilfsmittel, persönlichen Mitteilungen und Quellen in meiner Arbeit angegeben sind,

mich folgende Personen bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts unterstützt haben:

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die Hilfe eines Promotionsberaters nicht in Anspruch genommen wurde und dass Dritte weder unmittelbar noch mittelbar geldwerte Leistungen von mir für Arbeiten erhalten haben, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen,

dass ich die Dissertation noch nicht als Prüfungsarbeit für eine staatliche oder andere wissenschaftliche Prüfung eingereicht habe und dass ich die gleiche, eine

in wesentlichen Teilen ähnliche oder eine andere Abhandlung nicht bei einer anderen Hochschule als Dissertation eingereicht habe.

Diese Arbeit wurde unterstützt durch einen Max Planck Research Group Grant für Katharina von Kriegstein und weiterhin durch ein IZKF- Stipendium der Uni Jena für Carolin Otto.
Es lagen keine konkurrierenden finanziellen Interessen vor.

Ort, Datum Unterschrift der Verfasserin